Processing the Output of TOSOM

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ABSTRACT

The Threat Oriented Survivability Optimization Model (TOSOM) is a simple to use, first order model that permits the user to tradeoff various countermeasure technologies for the purpose of finding a countermeasure suite with enhanced survivability. The model postulates a threat environment, defines burdens (that is, constraints on any proposed solution), and also inputs various countermeasures that may improve the survivability in the given threat environment. The model then outputs various combinations of countermeasures, where each suite of countermeasures output by the model must satisfy the constraints placed upon any suite by the various burdens. Most importantly, associated with each suite of countermeasures is a level of survivability.

The goal of this paper is to examine the various methods for processing the output from a TOSOM run. The approach taken in processing TOSOM output depends to a great extent upon the philosophical position one takes toward the role of the burdens input while designing a particular study. This paper will examine two plausible but different philosophical positions together with their associated methods for processing the TOSOM output data.

INTRODUCTION

A brief description of what goes into the TOSOM model during a survivability study will be given. When TOSOM is executed, it creates eight output files. These eight files together with their content will be described. Two of these eight output files will be singled out for detailed attention, since they are the files containing the results of interest in a TOSOM study. Which file, of the two under consideration, to use in processing the results from a TOSOM study depends in large part upon the particular view the user has of burdens. These alternative views of burdens will be explained together with a technique for processing TOSOM output that is consistent with whichever view of burdens is adopted.

TOSOM

For a detailed description of the inputs TOSOM requires in the course of a survivability study, please see [1]. However, for the purpose of this paper it's sufficient to simply state that the inputs are threats, countermeasures, burdens, and connections between these three classes of data. The threat data consists of encounter, acquisition, hit, and kill

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probabilities. The countermeasure data describes each countermeasure. The burden data names each burden, and gives a maximum value for the burden. The remaining input data are the connections between threats and countermeasures, and the connections between burdens and countermeasures. For each threat-countermeasure pair, the effectiveness of the countermeasure against the threat is input. For each burden-countermeasure pair, the contribution of the countermeasure to the burden is input. When this array of input data is saved in TOSOM by the user it is given the filename, selected by the user, of FILENAME.TOS. This is one of the eight output files created by TOSOM, and it contains the data input into TOSOM by the user. In the next section a very simple example will be presented that will illustrate these inputs. The example will also be sufficient to elucidate the content of five of the remaining seven output files. The other two output files are the two of especial interest, and will be dealt with in later sections.

A VERY SIMPLE TOSOM EXAMPLE

This very simple example will be given the name: H2005. It will consist of a single threat, T, two countermeasures, CM-T and CM-NonT, and two burdens, Cost and Weight. (Note: This example is similar to one developed by Wallace Kistler, though the motivation for his example was rather different than the motivation for the present example.)

For threat T, the inputs are the probability of encounter, which in this case must be 1 since there is a single threat, and the probabilities of acquisition, hit, and kill which are arbitrarily assigned the values 1, .8, and .9 respectively.

The Cost burden is given a maximum value of 110. Note that the units are deliberately not specified, though in actual use there is a comment field in the model where units can be specified, and they can be whatever the user wishes, dollars, thousands of dollars, or any other convenient unit. The Weight burden is assigned a maximum value of 21, and a comment like that made for the Cost burden also applies here.

The effectiveness of CM-T against the threat T is assigned the value .8, and rather cavalierly CM-T is given a Cost burden of 20, and a Weight burden of 20. CM-NonT is also given an effectiveness of .8, with a Cost burden of 100, and a Weight burden of 1.

When this data is saved in TOSOM a file named H2005.TOS is created to store it. The filename is selected by the user, and the extension is added by the model. If, on the opening panel of TOSOM, the print key is clicked, then a summary of all input data is printed out.

When TOSOM is executed seven additional files are created. PARAM.DAT gives information on the number of countermeasures, burdens, and threats in the model. CM.DAT gives the effectiveness values for the countermeasures in the model. BURDEN.DAT gives the maximum value for each burden in the model, and the burden values for each countermeasure in the model. THREAT.DAT gives the probabilities of

encounter, acquisition, hit, and kill for each threat in the model. The four files created by TOSOM mentioned in this paragraph are not unique to a particular TOS file, but are associated with the last run of the model. Thus, care must be taken to make sure that the four data files mentioned in this paragraph are those of the model under consideration.

The three remaining files created by a run of the model all use the filename selected by the user, H2005 for the very simple example considered in this paper, and to these three files the model adds the extensions, KEY, DAT, and EEO respectively. The H2005.KEY file contains a list of the model's countermeasures together with their names, and a list of the model's burdens together with their names. The H2005.DAT and the H2005.EEO are the files of most interest in processing the output of TOSOM, and will each be given a section below.

However, before proceeding to an examination of H2005.DAT and H2005.EEO, note that a suite of countermeasures has a value for each burden. These values are determined by adding the burden values of the individual countermeasures that comprise the suite. For example, in H2005 the suite consisting of both CM-T and CM-NonT has a combined cost of 115 and a combined weight of 22, since CM-T has a Cost and Weight of 15 and 20, respectively, and CM-NonT has a Cost and Weight of 100 and 2, respectively. If a countermeasure suite has a burden value that exceeds the maximum for that burden, then that suite is not part of the output from TOSOM. Since the Cost maximum for H2005 is 110 and the Weight maximum is 21, the suite consisting ob both CM-T and CM-NonT will not be part of the output. To make the point again, if the Cost maximum had been 115 or higher and the Weight maximum had been 22 or higher, then the suite in H2005 consisting of CM-T and CM-NonT would have been part of the output.

ALL BURDENS ARE EQUAL

If the user of TOSOM thinks of burdens as true constraints, then USER-SELECTED-FILENAME.DAT (USF.DAT) is the file to use in processing output.

What is meant by considering burdens as true constraints? It means that all burdens are considered equal. Thus, among the countermeasure suites that satisfy all the burdens the desired suite will be the one with maximum survivability (or one of the suites with maximum survivability if there happens to be more than one).

For the very simple example of this paper, the user-selected-filename is H2005, so the file of interest here is H2005.DAT. Since there are two possible countermeasures in H2005, and since, as noted above, the suite containing both countermeasures violates a burden maximum, TOSOM will output only three of the four possible candidate countermeasure suites: (1) no countermeasures, that is, the baseline, (2) CM-T, and (3) CM-NonT. Simply read H2005.DAT into Excel obtaining:

0	0	0.720	0.280	0	0
1	0	0.144	0.856	15	20
2	0	0.144	0.856	100	2

Figure 1: H2005.DAT displayed in Excel

The first thing to note is that there are no labels. The second thing to note, though it's not apparent, is that not all of H2005.DAT is displayed. When H2005.DAT is read into Excel, the first column is empty; this column is not displayed. After the blank column, there are thirty columns devoted to listing the countermeasures in each suite. Since the maximum number of countermeasures in a H2005 suite is one (recall that the suite consisting of both countermeasures violated a burden), the last twenty-nine of the available thirty columns will consist of zeros. One of those zero columns is displayed above while the remaining twenty-eight have been deleted. The next column, the third column in Figure 1, is Lethality, which equals 1 – Survivability. The fourth column in Figure 1 is Survivability. Then there are a number of columns equal to the number of burdens in the TOSOM study; in the case of H2005, there will be two burden columns, Cost and Weight. The first burden column, column 5 above, is Burden 1, which, from the H2005.KEY file, is Cost. The second burden column is Burden 2, which, again from the H2005.KEY file, is Weight.

Each row in Figure 1 corresponds to a suite of countermeasures. The first row is the baseline; the second row is the suite consisting of only countermeasure 1, which from the H2005.KEY file is CM-T; the third row is the suite with only countermeasure 2, which again from the H2005.KEY file is CM-NonT. For each suite the Survivability column gives the survivability of that suite, and the burden columns give the burden values for the suite.

In Figure 1 it's seen that there are two suites with maximum survivability. Which suite is selected as the survivability solution should be a matter of indifference. If it's not, then perhaps the next section will be more to your liking.

SOME BURDENS ARE MORE BURDENSOME THAN OTHERS

If the user of TOSOM feels or thinks that the choice between the equal survivability solutions, CM-T or CM-NonT, offered above should be something other than random, then USER-SELECTED-FILENAME.EEO (USF.EEO) is the file to use in processing output. For example, if the user thinks that cost is more important than weight, then he or she would choose CM-T with lower cost but higher weight. If, on the other hand, weight is considered the more important burden, then CM-NonT would be the logical choice. Using USF.EEO to process TOSOM output offers a methodology for formalizing such choices.

The first step in using USF.EEO to process TOSOM output is to read USF.EEO into the program TOSOM-AHP. TOSOM-AHP has one potential problem and one glaring mis-labeling, both of which will be discussed in what follows. In order to discuss both the

potential problem and the mis-labeling, it's necessary to provide a brief summary of how TOSOM-AHP functions.

The initial screen in TOSOM-AHP has five tabs: File_Selection (which is where the user would read in USF.EEO), Verbal, Matrix (these two tabs are the heart of the program's setup and perform the same function but in different fashions), Calculate (which calculates the weightings for each burden), and Output.

If the user clicks on the Matrix tab, she's presented with an n-by-n matrix where n is always one greater than the number of burdens. Thus, in H2005 the matrix tab will present a 3-by-3 matrix since there are two burdens. The H2005 matrix will look like:

	P(s)	Cost	Weight
P(s)	1.00		
Cost		1.00	
Weight			1.00

Figure 2: H2005.EEO in TOSOM.AHP

The important thing to note here, and the potential problem, is that Survivability is treated as just another burden.

If the user clicks on the Auto Fill button, the matrix will be filled in with 1.00s, giving:

	P(s)	Cost	Weight
P(s)	1.00	1.00	1.00
Cost	1.00	1.00	1.00
Weight	1.00	1.00	1.00

Figure 3: Completed matrix in TOSOM.AHP

The interpretation of this default filling of the AHP-matrix is that all burdens are equal; that is, the user is back at the case already considered above but with one very important difference, which is that now Survivability is just another burden.

Now, with regard to burdens low values are good. Low Cost is good, and low Weight is good. However, low Survivability is not good, and this is the source of the mis-labeling, because the values used for Survivability are not the Survivability values but the Lethality = 1 – Survivability values. Note that low Lethality values mean high Survivability values which is good, and therefore low AHP-scores are the good scores, low Cost, low Weight, low Lethality. Before explaining how to get TOSOM-AHP to compute the scores, let's make an observation: Since Lethality (Survivability) is just another burden, and all burdens are equal, the baseline will be the best solution, since it is superior in two of the three burdens. This is TOSOM-AHP's potential problem, but more about that later.

It the user of TOSOM-AHP clicks on the Calculate tab, she'll see the list of burdens (again with Lethality mis-labeled P(s)). For H2005 the list will be: P(s) with minimum .144 and maximum .720; Cost with min 0 and max 100; and Weight with min 0 and max 20. Note that the values given for P(s) are the Lethality values (see Figure 1). The weightings given for the three burdens will, at this point, all be 0. If the user now clicks on the Process Preferences button, then the weights for the burdens will be calculated and displayed, and in this instance they will all be equal to .333.

How are these weightings calculated? An n-by-n AHP-matrix will always have an eigenvalue greater than or equal to n. Associated with that eigenvalue will be an eigenvector of all positive entries with the sum of the entries equal to 1. Those entries will be the weights of the burdens.

After the weights are calculated in the H2005 example, the user can click the Output tab and then click the OK button. A results matrix is presented that looks like:

Record Number	AHP Score	P(s)	Cost	Weight	CM-T	CM-NonT
1	0.38333	0.14	15.00	20.00	Cm-T	
2	0.36667	0.14	100.00	2.00		CM-NonT
3	0.33333	0.72	0.00	0.00		

Figure 4: H2005 results matrix in TOSOM-AHP

The first thing to note is that P(s) should be labeled Lethality, another instance of the mis-labeling problem. Secondly, since low scores are good, the user sees that, as noted above, the baseline is the preferred solution, which is not at all what one really believes. CM-NonT is the second best solution, and CM-T is the worst solution.

Why is CM-T a worse solution than CM-NonT? CM-T is at max Weight and at 15% of max Cost, while CM-NonT is at max Cost, but only 10% of max Weight. Since Cost and Weight are given equal weight, CM-NonT wins.

The AHP-matrix will be revisited in a more useful fashion below. However, before that, let's explain how AHP-scores are actually calculated. The min Weight is 0, which is associated with a score of 0; the max Weight is 20 which is associated with a score of 1. This gives two (Weight, Weight-score)-points; namely, (0, 0) and (20, 1). The line through these two points is:

$$\text{Weight-score} = \text{Weight}/20$$

From this equation, the Weight-score for any given Weight can be determined. In a similar fashion, equations can be found that allow the calculation of Cost-score in terms of Cost, and Lethality-score in terms of Lethality. Then the AHP-score is determined by

AHP-score = Lethality-weight x Lethality score
+ Cost-weight x Cost-score
+ Weight-weight x Weight-score

Now that we understand how TOSOM-AHP functions, let's return to H2005 and see how we could use it to actually help us solve the problem of selecting an appropriate suite. Again the user would start with the opening AHP-matrix as illustrated below once again.

	P(s)	Cost	Weight
P(s)	1.00		
Cost		1.00	
Weight			1.00

Lethality is very likely considerably more important than any other burden. Which of Cost and Weight is more important? It's up to the user. For illustrative purposes, let's suppose that Cost is more important by a factor of 2. That would give

	P(s)	Cost	Weight
P(s)	1.00		
Cost		1.00	2.00
Weight			1.00

If Cost is twice as important as Weight, then Weight is half as important as Cost, so the matrix must look like:

	P(s)	Cost	Weight
P(s)	1.00		
Cost		1.00	2.00
Weight		0.50	1.00

Whatever value the user specifies (within certain constraints) for the entry a_{ij}, TOSOM-AHP automatically calculates a_{ji} as $1/a_{ij}$. Thus, if the user enters the 2.00 in the matrix, TOSOM-AHP enters the 0.50; if the user would have entered the 0.50, TOSOM-AHP would have entered the 2.00.

TOSOM-AHP only allows 1 through 9 and their reciprocals (automatically rounded to two decimal places) as entries in the AHP-matrix, though clearly no such restriction is inherent in the process.

Continuing, let's suppose that Lethality is four times more important than Cost, so that the matrix looks like:

	P(s)	Cost	Weight
P(s)	1.00	4.00	
Cost	0.25	1.00	2.00
Weight		0.50	1.00

Now, since Lethality is four times more important than Cost, and Cost is twice as important as Weight, consistency dictates that Lethality be eight time more important than Weight, so that the final matrix looks like:

	P(s)	Cost	Weight
P(s)	1.00	4.00	8.00
Cost	0.25	1.00	2.00
Weight	0.13	0.50	1.00

The first thing to note is that 1/8 = 0.125 was rounded to 0.13. The second point concerns the consistency of the AHP-matrix. As already mentioned, if the entries above the diagonal are filled in, then TOSOM-AHP automatically fills in the entries below the diagonal. Thus, the user is at liberty to fill the entries above the diagonal in any fashion she chooses, subject to the constraints already mentioned. However, once the first row of the AHP-matrix is filled, then every burden is measured in terms of Lethality, and therefore their relation to each other is determined. This is the point: TOSOM-AHP does not force the user to be consistent; that is, she can fill the entries above the diagonal but not in the first row in an inconsistent fashion. Why one would do this is the topic of another discussion.

Using the above AHP-matrix, we can now proceed with our analysis. Clicking the Calculate tab, and then the Process Preferences button provides the weights: Lethality-weight = 0.72727; Cost-weight = 0.18182; and Weight-weight = 0.09091. As expected, Lethality is weighted four times more than Cost, and Cost is weighted twice than of Weight. If the user now clicks the Output tab, and then the OK button, the AHP-results-matrix given below is displayed.

Record Number	AHP Score	P(s)	Cost	Weight	CM-T	CM-NonT
1	0.72727	0.72	0.00	0.00		
2	0.19091	0.14	100.00	2.00		CM-NonT
3	0.11818	0.14	15.00	20.00	CM-T	

Here CM-T has the lowest score and would be the preferred solution. This should not be surprising given our weightings and the simplicity of the example, but it also handily illustrates the usefulness of TOSOM and TOSOM-AHP to the analyst.

SUMMARY

Two methods for processing the output from a TOSOM study were illustrated. In one, burdens constrain the solution space, but are then ignored, with the solution depending upon the survivability level. In the second method, burdens once again constrain the solution space, but are then considered as having varying weights, with the solution depending upon a score determined by both survivability and the variously weighted burdens.

In a future paper, we'll discuss a variant of TOSOM-AHP, developed by Wallace Kistler at Teledyne-Brown Engineering, that corrects the mis-labeling problem mentioned several times in the current paper, and also exempts Survivability (Lethality) from being just another burden. It's hoped that in the near future the variant version of TOSOM-AHP together with the current version will both be included as part of the official TOSOM modeling package.

REFERENCES

[1] William Jackson, Daniel Hicks, Jack Reed, "Data Requirements for TOSOM," Proceedings of the Ground Vehicle Survivability Symposium 2005, 11-14 April 2005, Naval Postgraduate School, Monterey, California, to be released.